FIG. 1

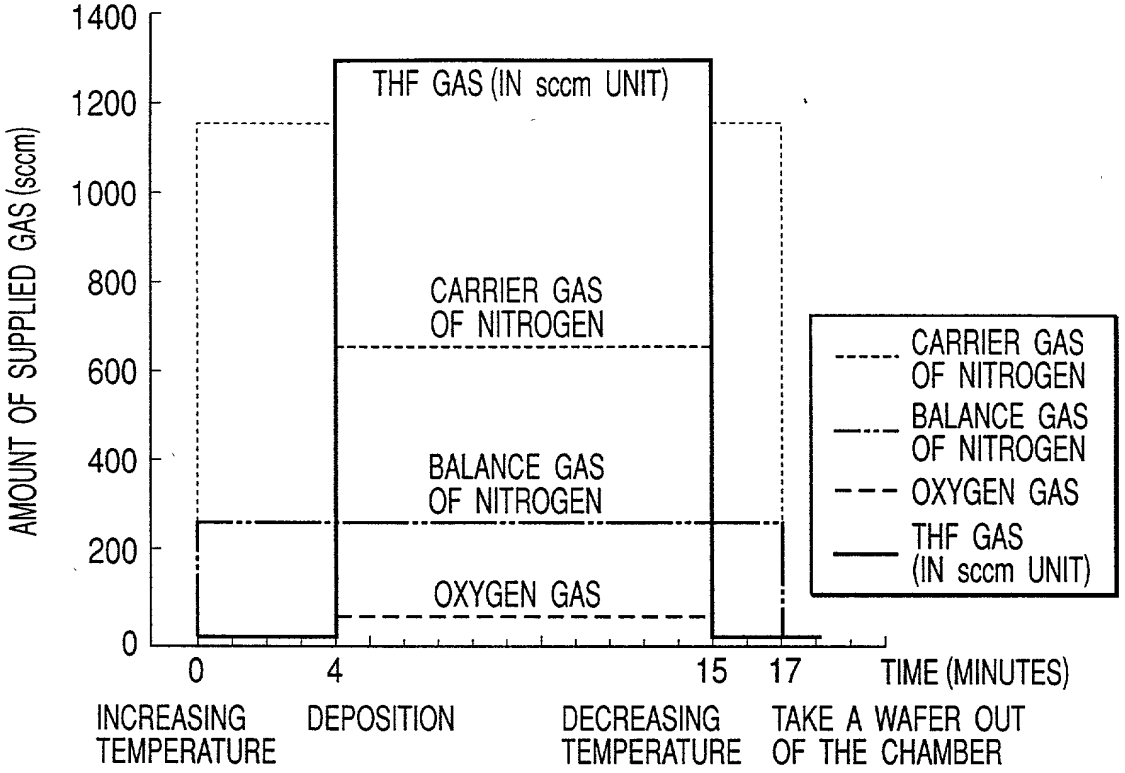

1400
1200
1000
800
600
400
200
0
AMOUNT OF SUPPLIED GAS (sccm)
THF GAS (IN sccm UNIT)
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
0
4
15
17
TIME (MINUTES)
INCREASING TEMPERATURE
DEPOSITION
DECREASING TEMPERATURE
TAKE A WAFER OUT OF THE CHAMBER
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
THF GAS (IN sccm UNIT)

FIG. 2

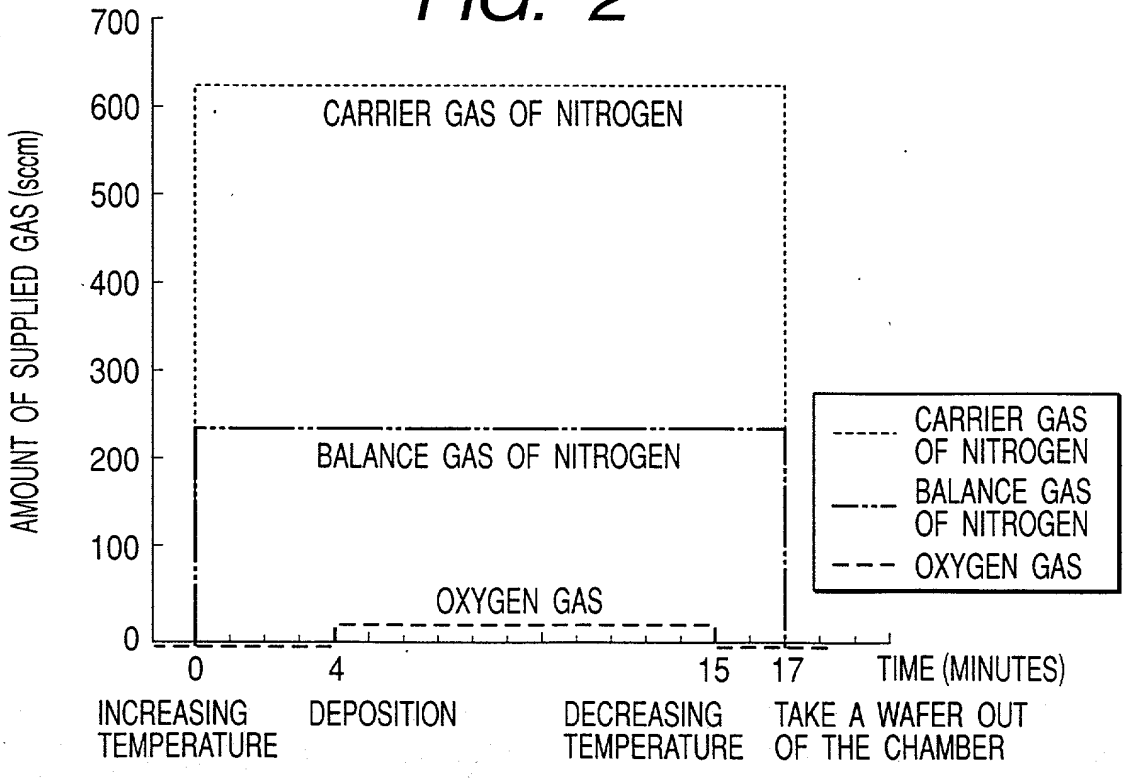

700
600
500
400
300
200
100
0
AMOUNT OF SUPPLIED GAS (sccm)
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
0
4
15
17
TIME (MINUTES)
INCREASING TEMPERATURE
DEPOSITION
DECREASING TEMPERATURE
TAKE A WAFER OUT OF THE CHAMBER
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS

FIG. 3(a)

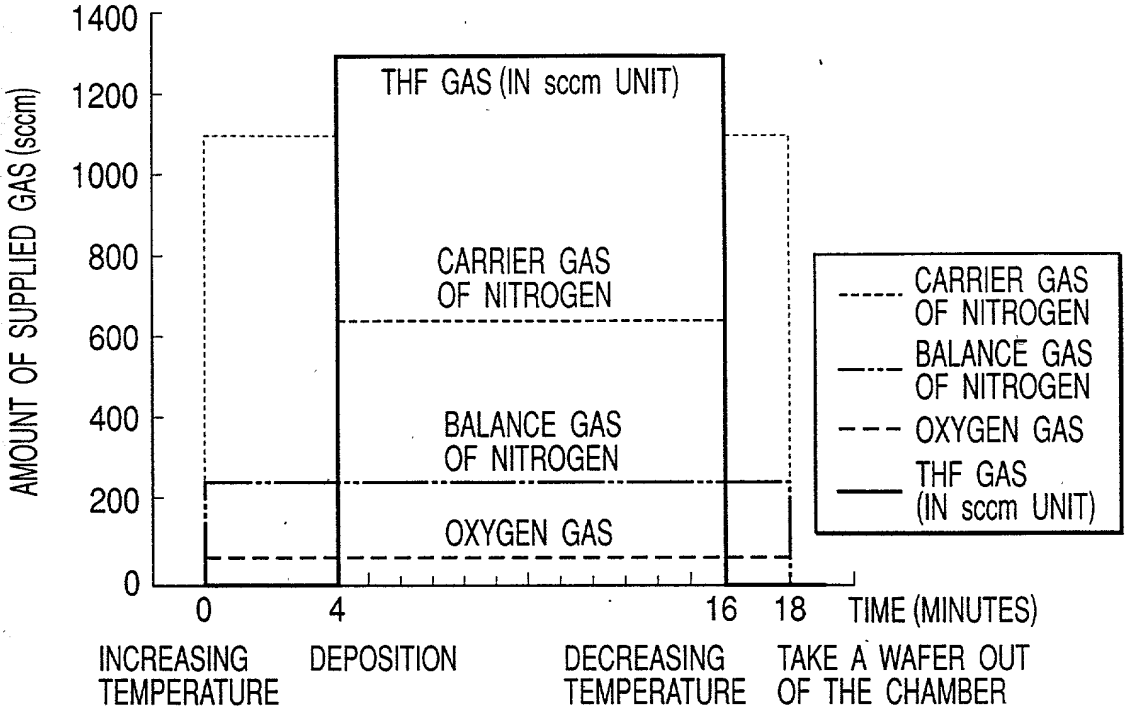

AMOUNT OF SUPPLIED GAS (sccm)
1400
1200
1000
800
600
400
200
0
THF GAS (IN sccm UNIT)
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
0
4
16
18
TIME (MINUTES)
INCREASING TEMPERATURE
DEPOSITION
DECREASING TEMPERATURE
TAKE A WAFER OUT OF THE CHAMBER
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
THF GAS (IN sccm UNIT)

FIG. 3(b)

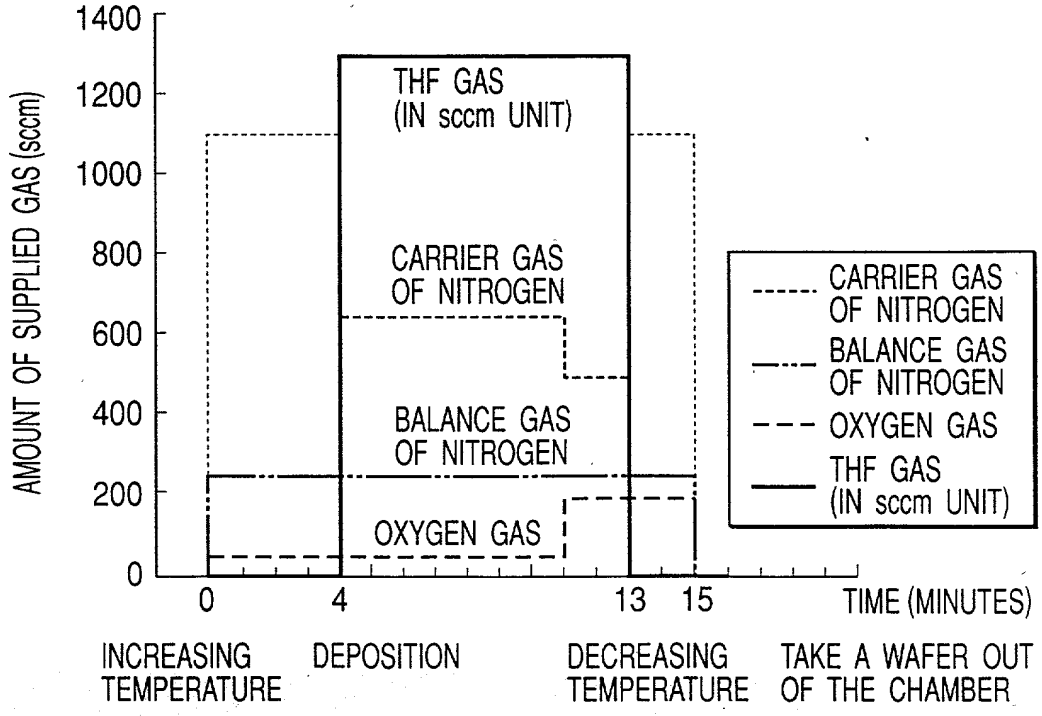

AMOUNT OF SUPPLIED GAS (sccm)
1400
1200
1000
800
600
400
200
0
THF GAS (IN sccm UNIT)
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
0
4
13
15
TIME (MINUTES)
INCREASING TEMPERATURE
DEPOSITION
DECREASING TEMPERATURE
TAKE A WAFER OUT OF THE CHAMBER
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
THF GAS (IN sccm UNIT)

FIG. 4(a)

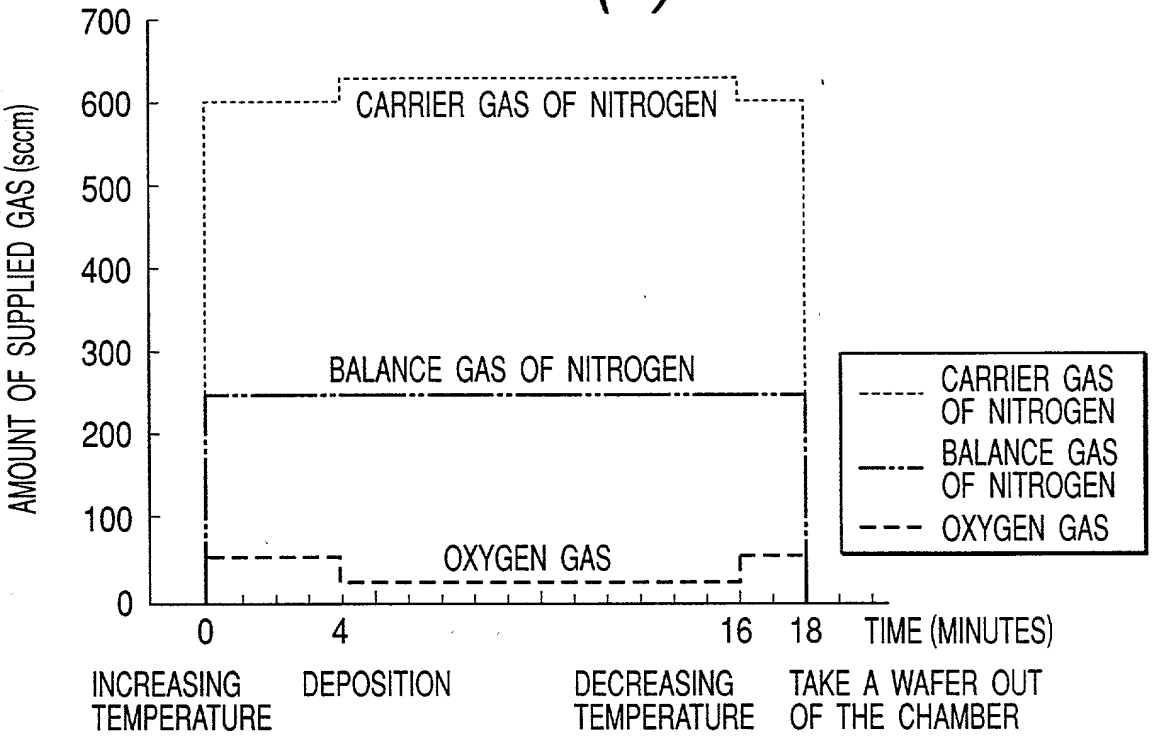

700
600
500
400
300
200
100
0
AMOUNT OF SUPPLIED GAS (sccm)
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
0
4
16
18
TIME (MINUTES)
INCREASING TEMPERATURE
DEPOSITION
DECREASING TEMPERATURE
TAKE A WAFER OUT OF THE CHAMBER
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS

FIG. 4(b)

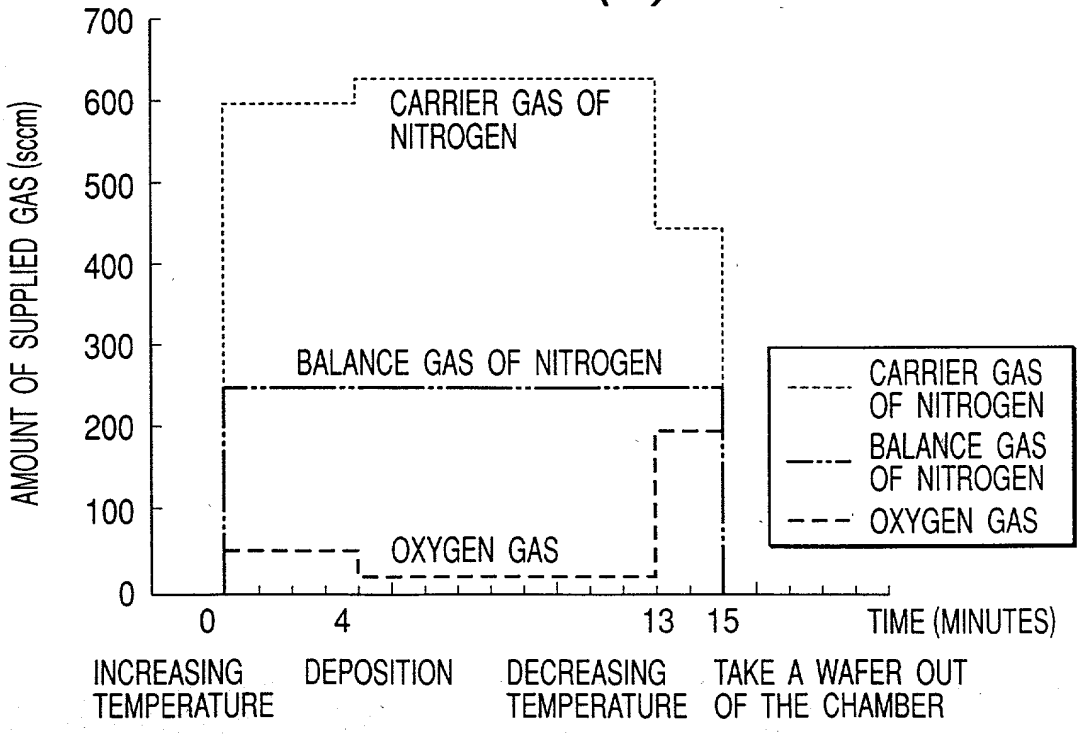

700
600
500
400
300
200
100
0
AMOUNT OF SUPPLIED GAS (sccm)
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS
0
4
13
15
TIME (MINUTES)
INCREASING TEMPERATURE
DEPOSITION
DECREASING TEMPERATURE
TAKE A WAFER OUT OF THE CHAMBER
CARRIER GAS OF NITROGEN
BALANCE GAS OF NITROGEN
OXYGEN GAS

FIG. 5(a)

RECIPE NO.	PRECURSOR OF CHEMICAL VAPOR DEPOSITION	RUTHENIUM SEED LAYER	EXPERIMENTAL CONDITIONS	CVD GROWTH TEMPERATURE (°C)	STEP 1 : INCREASING THE WAFER TEMPERATURE	STEP 2 : SUPPLYING THE PRECURSOR	STEP 3 : DECREASING THE WAFER TEMPERATURE	AMOUNT OF OXYGEN CONTAMINATION atom/cm^2
1	$Ru(C_5H_4C_2H_5)_2$	NON LAYER	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220–270	650 20 250 920 5	650 20 250 920 5	650 20 250 920 5	7.0E+15
2	$Ru(C_5H_4C_2H_5)_2$	NON LAYER	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220–270	650 20 250 920 5	650 20 250 920 5	650 20 250 900 5	5.0E+14
3	$Ru(C_5H_4C_2H_5)_2$	NON LAYER	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220–270	650 0 250 900 5	650 20 250 920 5	650 20 250 920 5	7.0E+15
4	$Ru(C_5H_4C_2H_5)_2$	NON LAYER	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220–270	650 0 250 900 5	650 20 250 920 5	650 0 250 900 5	<1E14
5	$Ru(C_5H_4C_2H_5)_2$	NON LAYER	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220–270	650 0 250 900 5	650 500 250 1400 5	650 0 250 900 5	1.0E+17

FIG. 5(b)

RECIPE NO.	PRECURSOR OF CHEMICAL VAPOR DEPOSITION	RUTHENIUM SEED LAYER	EXPERIMENTAL CONDITIONS	CVD GROWTH TEMPERATURE (°C)	STEP 1 : INCREASING THE WAFER TEMPERATURE	STEP 2 : SUPPLYING THE PRECURSOR	STEP 3 : DECREASING THE WAFER TEMPERATURE	AMOUNT OF OXYGEN CONTAMINATION atom/cm²
6	$Ru(C_5H_4C_2H_5)_2$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220~270	650 20 250 920 5	650 20 250 920 5	650 0 250 900 5	2.0E+15
7	$Ru(C_5H_4C_2H_5)_2$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220~270	650 20 250 900 5	650 20 250 920 5	650 20 250 920 5	7.0E+15
8	$Ru(C_5H_4C_2H_5)_2$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220~270	650 20 250 900 5	650 20 250 920 5	650 0 250 900 5	<1E14
9	$Ru(C_5H_4C_2H_5)_2$ /THF 0.1mol/1	NON LAYER	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) THF GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	270~350	1150 0 0 250 1400 5	650 50 1300 250 2250 5	1150 0 0 250 1400 5	<1E14
10	$Ru(C_5H_4C_2H_5)_2$ /THF 0.1mol/1	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) THF GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	270~350	1150 0 0 250 1400 5	650 50 1300 250 2250 5	1150 0 0 250 1400 5	<1E14

FIG. 6

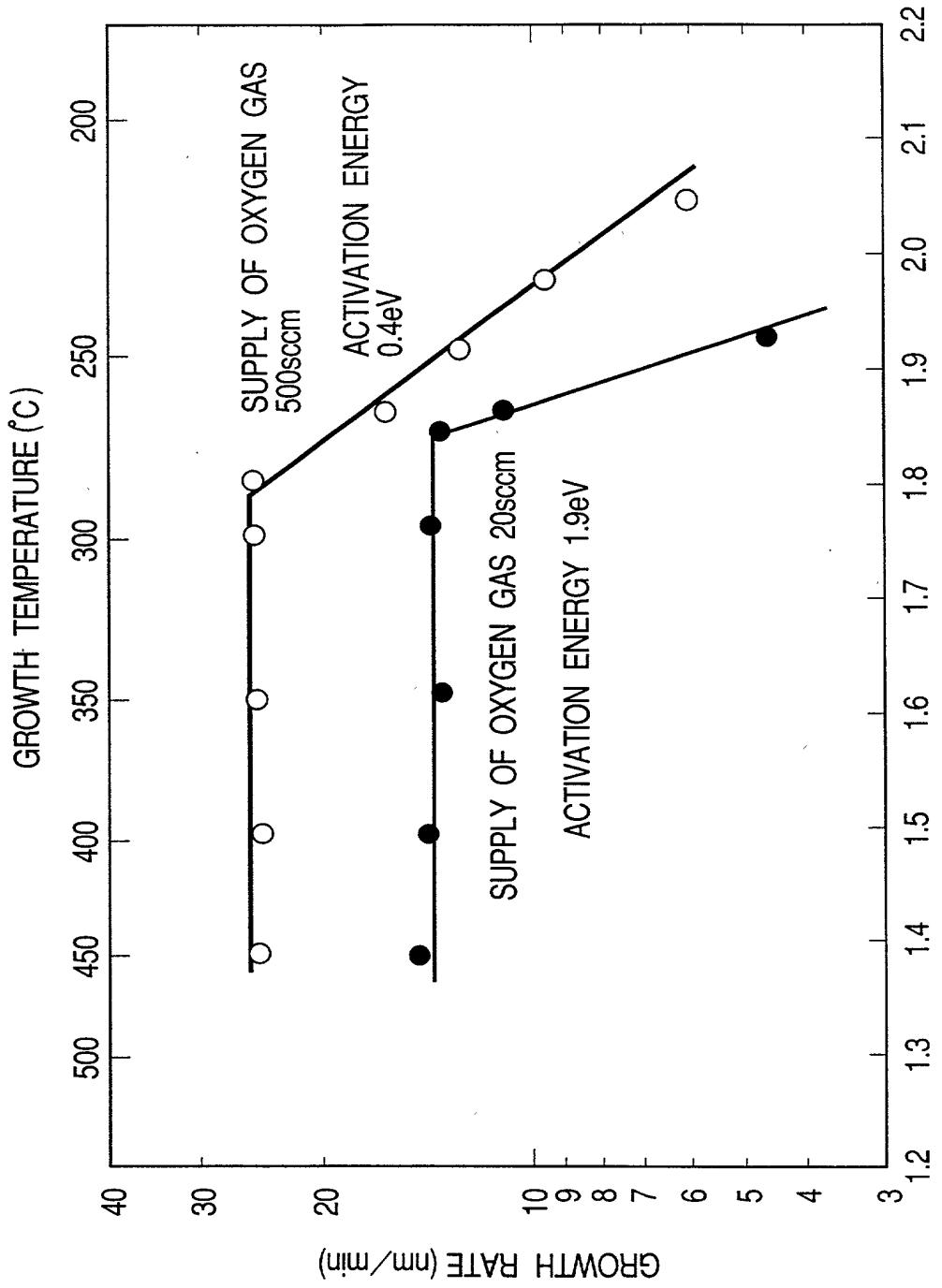

GROWTH TEMPERATURE (°C)
500
450
400
350
300
250
200
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
1/T (1000/K)
GROWTH RATE (nm/min)
40
30
20
10
9
8
7
6
5
4
3
SUPPLY OF OXYGEN GAS
500sccm
ACTIVATION ENERGY
0.4eV
SUPPLY OF OXYGEN GAS 20sccm
ACTIVATION ENERGY 1.9eV

FIG. 7

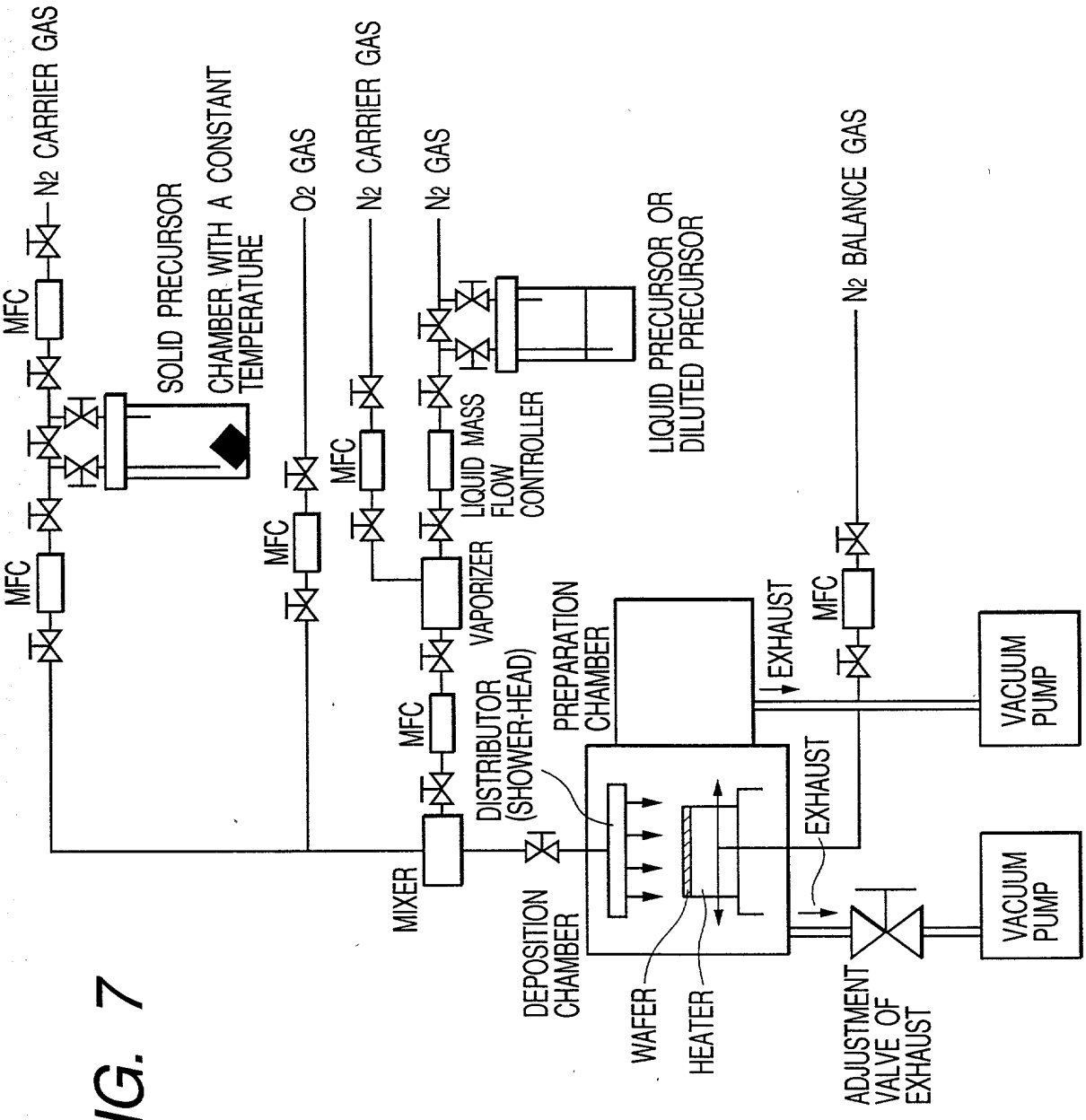

MFC
N2 CARRIER GAS
SOLID PRECURSOR
CHAMBER WITH A CONSTANT TEMPERATURE
MFC
O2 GAS
MFC
N2 CARRIER GAS
MFC
N2 GAS
LIQUID MASS FLOW CONTROLLER
LIQUID PRECURSOR OR DILUTED PRECURSOR
VAPORIZER
MFC
DISTRIBUTOR (SHOWER-HEAD)
PREPARATION CHAMBER
EXHAUST
MFC
N2 BALANCE GAS
MIXER
DEPOSITION CHAMBER
WAFER
HEATER
EXHAUST
VACUUM PUMP
ADJUSTMENT VALVE OF EXHAUST
VACUUM PUMP

FIG. 8(a)

RECIPE NO.	PRECURSOR OF CHEMICAL VAPOR DEPOSITION	RUTHENIUM SEED LAYER	EXPERIMENTAL CONDITIONS	CVD GROWTH TEMPERATURE (°C)	STEP 1 : INCREASING THE WAFER TEMPERATURE	STEP 2 : SUPPLYING THE PRECURSOR	STEP 3 : DECREASING THE WAFER TEMPERATURE	AMOUNT OF OXYGEN CONTAMINATION atom/cm^2
11	$Ru(C_5H_5)_2$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220—270	650 0 250 900 5	650 20 250 920 5	650 0 250 900 5	<1E14
12	$Ru(C_5H_4CH_3)_2$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220—270	650 0 250 900 5	650 20 250 920 5	650 0 250 900 5	<1E14
13	$Ru(C_{11}H_{19}O_2)_3$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220—280	650 0 250 900 5	650 20 250 920 5	650 0 250 900 5	5.0E+14
14	$Ru(OD)_3$	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	240—300	650 0 250 900 5	650 20 250 920 5	650 0 250 900 5	6.0E+14
15	$Ru(C_5H_4C_2H_5)_2$ /CH_3OH 0.1mol/1	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) CH30H GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	250—350	1150 0 0 250 1400 5	650 100 2800 250 3800 5	1150 0 0 250 1400 5	<1E14

FIG. 8(b)

RECIPE NO.	PRECURSOR OF CHEMICAL VAPOR DEPOSITION	RUTHENIUM SEED LAYER	EXPERIMENTAL CONDITIONS	CVD GROWTH TEMPERATURE (°C)	STEP 1 : INCREASING THE WAFER TEMPERATURE	STEP 2 : SUPPLYING THE PRECURSOR	STEP 3 : DECREASING THE WAFER TEMPERATURE	AMOUNT OF OXYGEN CONTAMINATION atom/cm^2
16	$Ru(C_5H_4C_2H_5)_2$ /C_8H_{18} 0.1mol/1	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) C_8H_{11} GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	250—350	1150 0 0 250 1400 5	650 50 690 250 1640 5	1150 0 0 250 1400 5	<1E14
17	$Ru(C_5H_5)_2$/THF 0.1mol/1	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) THF GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	260—350	1150 0 0 250 1400 5	650 50 1300 250 2250 5	1150 0 0 250 1400 5	<1E14
17	$Ru(C_{11}H_{19}O_2)_3$ /THF 0.1mol/1	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) THF GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220—350	1150 0 0 250 1400 5	650 50 1300 250 2250 5	1150 0 0 250 1400 5	3.0E+14
18	$Ru(CD)_3$/THF 0.1mol/1	1nm~2nm	N_2 CARRIER GAS(sccm) OXYGEN GAS(sccm) THF GAS(sccm) N_2 BALANCE GAS(sccm) TOTAL AMOUNT OF SUPPLIED GASES(sccm) PRESSURE(Torr)	220—350	1150 0 0 250 1400 5	650 50 1300 250 2250 5	1150 0 0 250 1400 5	4.0E+14

FIG. 9

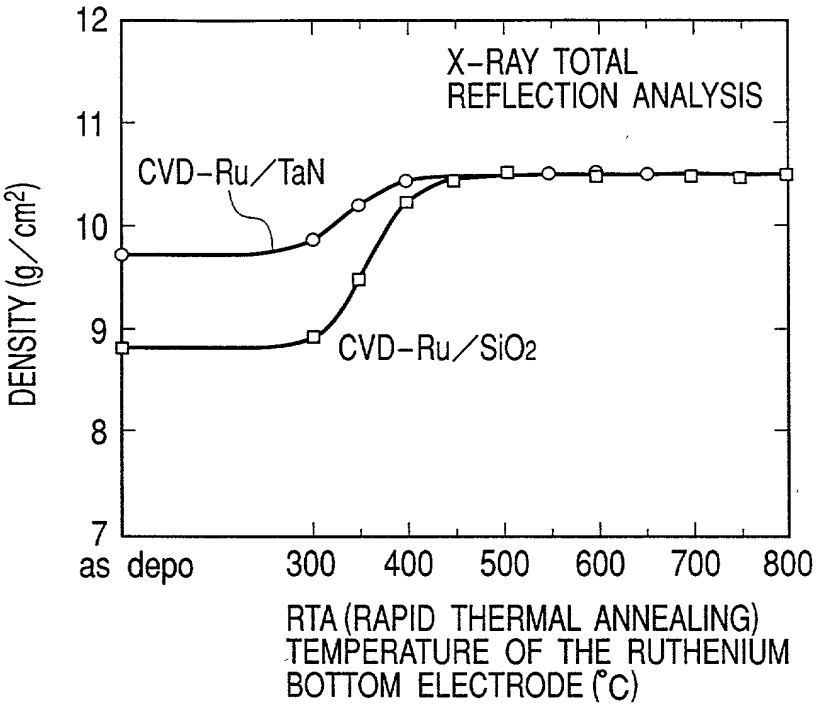

X-RAY TOTAL
REFLECTION ANALYSIS
CVD-Ru/TaN
CVD-Ru/SiO2
DENSITY (g/cm²)
12
11
10
9
8
7
as depo
300
400
500
600
700
800
RTA (RAPID THERMAL ANNEALING)
TEMPERATURE OF THE RUTHENIUM
BOTTOM ELECTRODE (°C)

FIG. 10

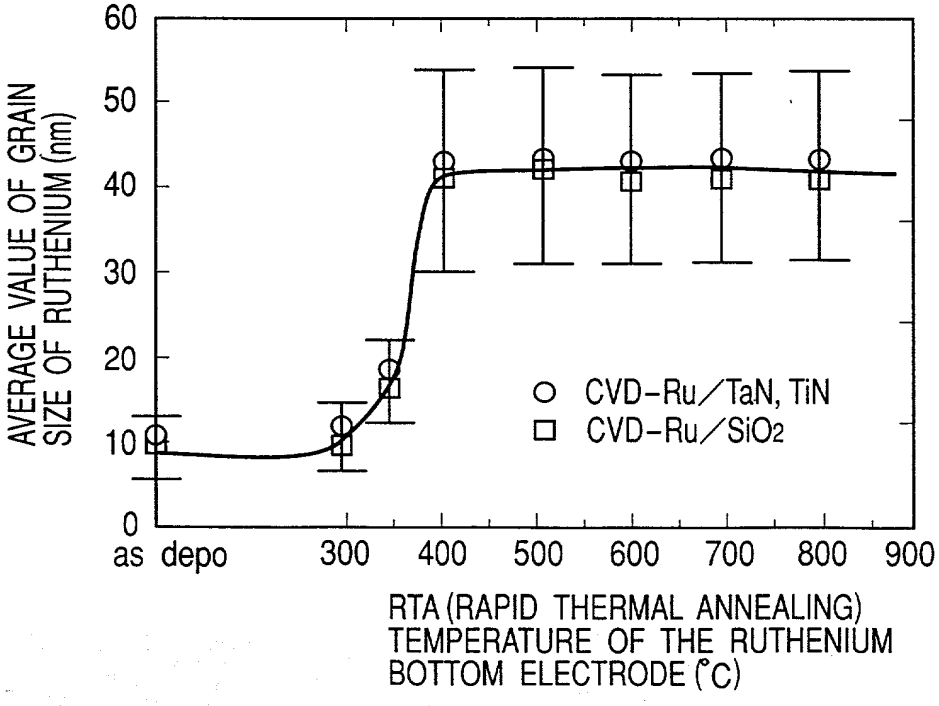

AVERAGE VALUE OF GRAIN
SIZE OF RUTHENIUM (nm)
60
50
40
30
20
10
0
CVD-Ru/TaN, TiN
CVD-Ru/SiO2
as depo
300
400
500
600
700
800
900
RTA (RAPID THERMAL ANNEALING)
TEMPERATURE OF THE RUTHENIUM
BOTTOM ELECTRODE (°C)

FIG. 11

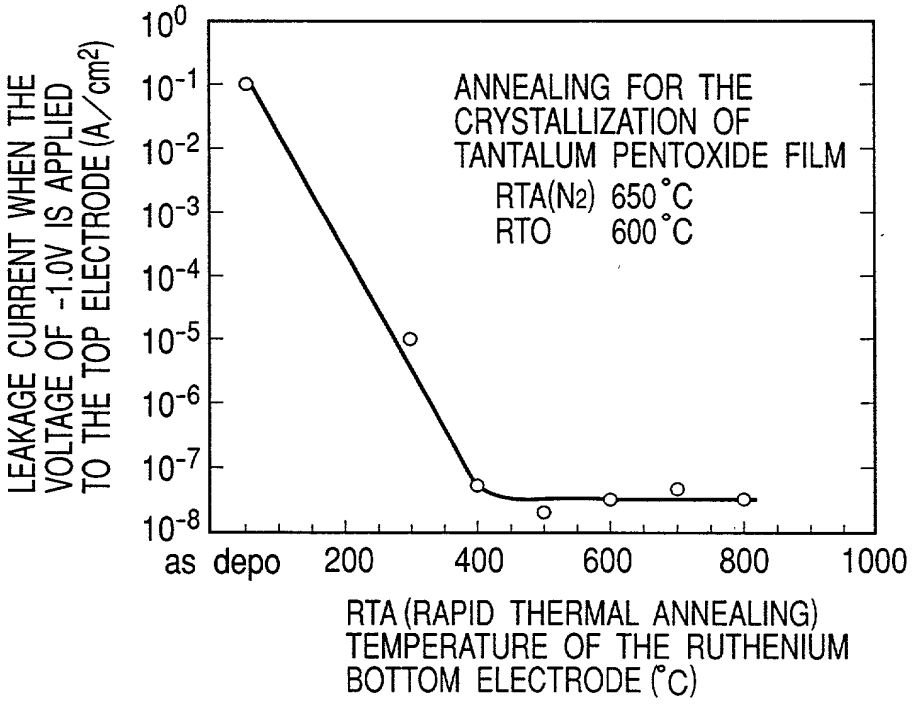

LEAKAGE CURRENT WHEN THE VOLTAGE OF -1.0V IS APPLIED TO THE TOP ELECTRODE (A/cm²)
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
ANNEALING FOR THE CRYSTALLIZATION OF TANTALUM PENTOXIDE FILM
RTA(N2) 650°C
RTO 600°C
as depo
200
400
600
800
1000
RTA (RAPID THERMAL ANNEALING) TEMPERATURE OF THE RUTHENIUM BOTTOM ELECTRODE (°C)

FIG. 12(a)

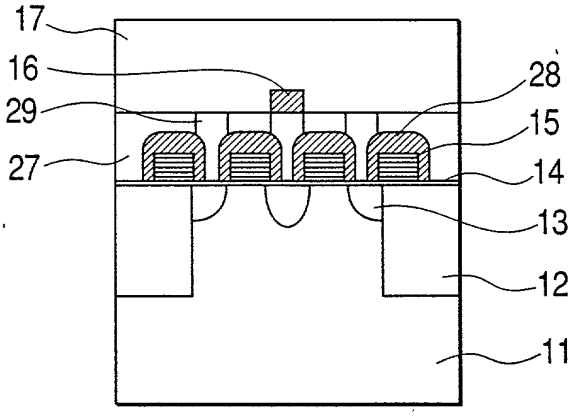


FIG. 12(b)

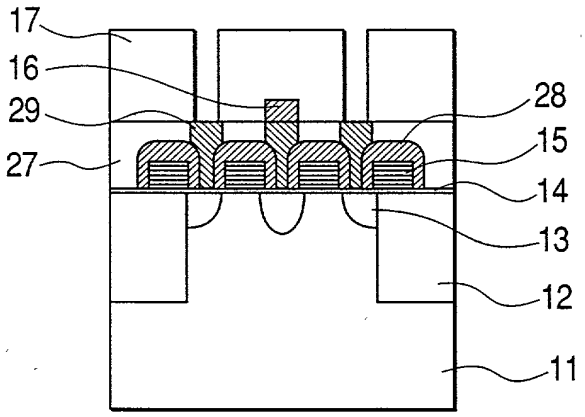


FIG. 12(c)

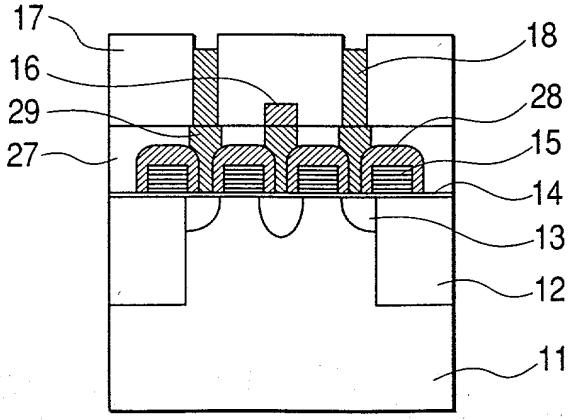


FIG. 13(a)

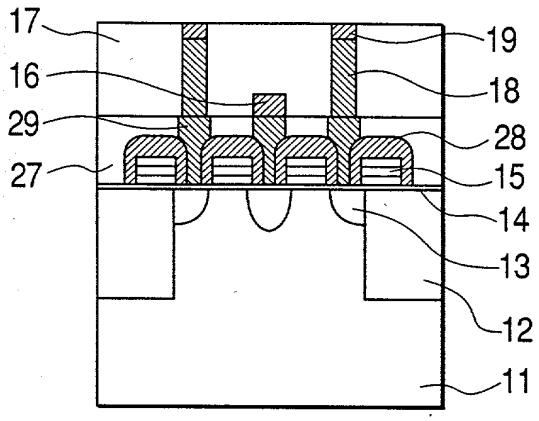


FIG. 13(b)

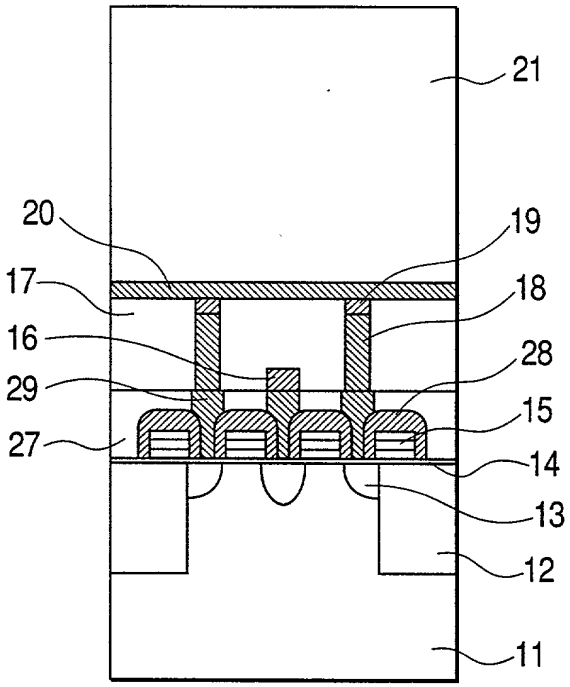


FIG. 13(c)

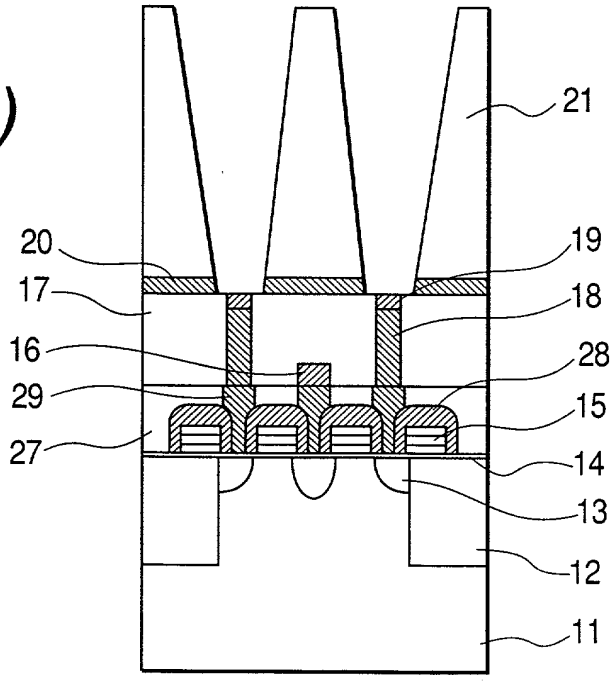


FIG. 14(a)

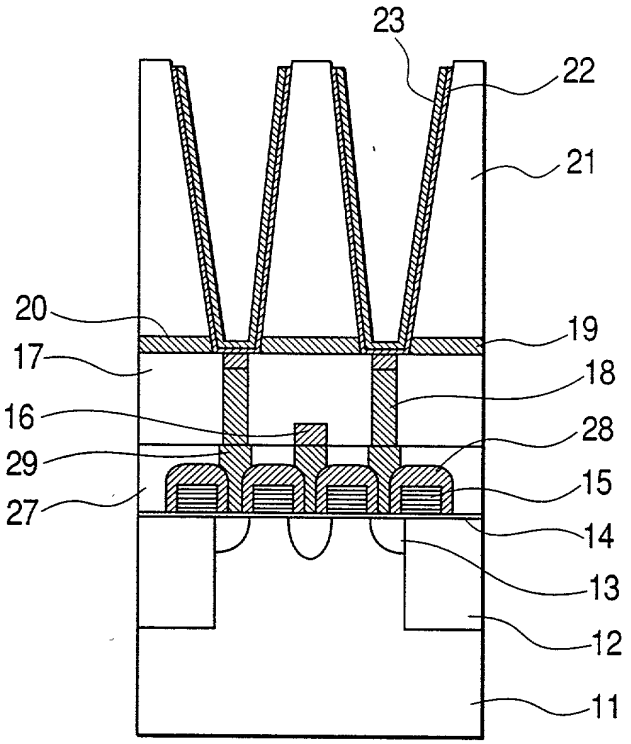


FIG. 14(b)

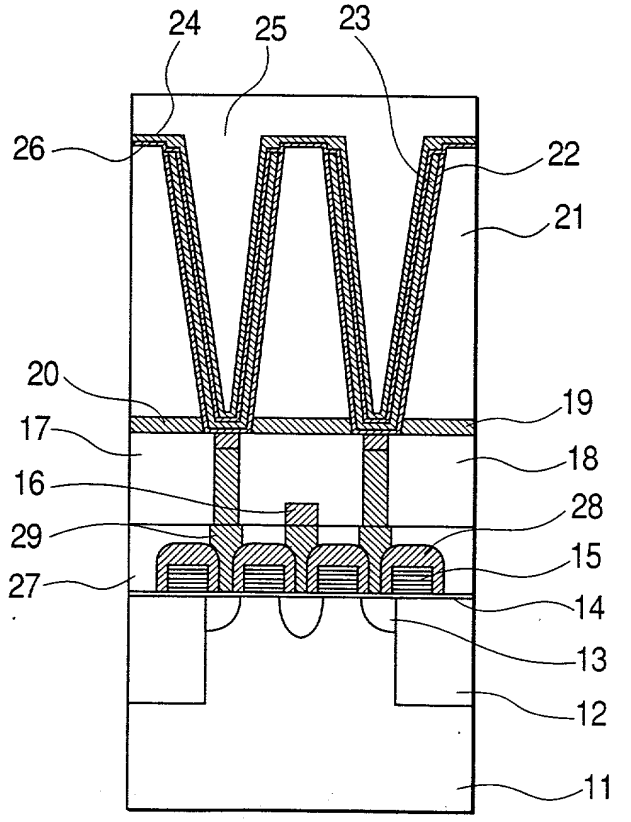
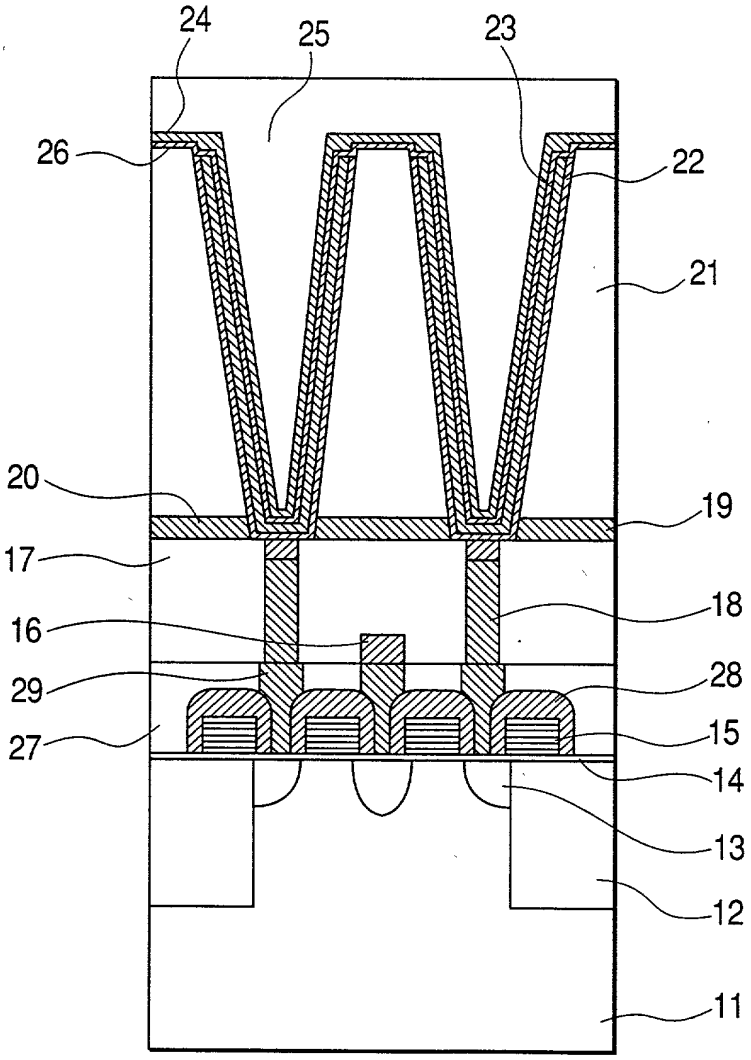


FIG. 15



ENLARGED FIGURE OF FIG. 14(b)

FIG. 16(a)
PRIOR ART

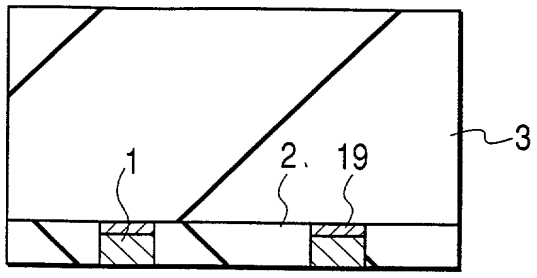


FIG. 16(b)
PRIOR ART

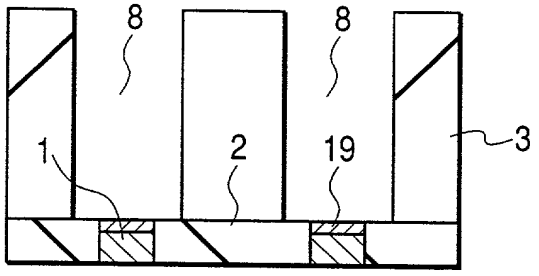


FIG. 16(c)
PRIOR ART

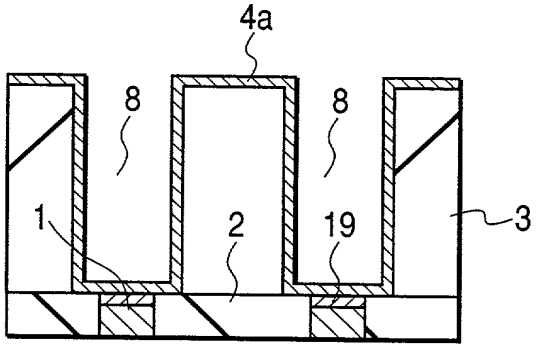


FIG. 16(d)
PRIOR ART

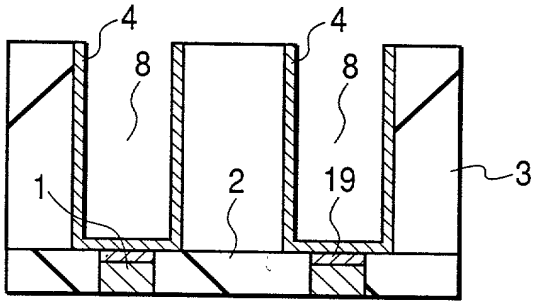


FIG. 16(e)
PRIOR ART